

Comparison of Photovoltaic Module Performance Measurements

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Overview

- Objectives/Scope
- Experimental Apparatus
- Methods of Test
- Experimental Results
- Summary

Objectives

- Compare Photovoltaic Module Characteristics Measured at Two Outdoor Test Facilities
- Obtain PV Simulation Model Input Parameters

The screenshot displays the PV-DesignPro-S v6.0 software interface. The main window is titled "NIST Modeling Analysis" and contains the following information:

- Location Data:** Latitude: 39.1329, Longitude: 77.2171, Stan. Merid.: 75, Elevation(m): 154.84.
- Input File:** (INPUT FILES)\Monthly Continuous Data\5min_Avg_PSPCOR_NS_0
- Irradiance Calculation:** Use Measured Vertical Irradiance (selected).
- Diffuse Irradiance:** Use Measured Diffuse Irradiance (selected).
- Temperature Calculation:** Use Sandia Calculated Module Temperature (selected).
- Select Panel:** Panel A (selected).
- ASCII Input File Data Delimiter:** Tab (selected).
- Select Outputs:** A list of parameters including HorExtraRadW_m2, DirBeamRadW_m2, SolarDeclinationDeg, EquationOfTimeMin, SolarTimeMin, HourAngleDeg, SolarAzimuthDeg, ModuleSlopeDeg, ArrayAzimuth, AngOfIncidenceDeg, ZenithAngDeg, RatioBeamRad_Rb, RadOnArrayW_m2, ArrayOperVoltage, PVCellTempCel, AbsAirMass, Fl_AMa, r2_AOI, Isc, and Imp.

The "PV System Array Configuration" window is also visible, showing the following parameters:

- Panel A - a,b,d(Tc) corrected 2001 c-Si
- 1 Number of Parallel Module Connection Strings
- 1 Number of Modules in Each Parallel String
- 1.6284 Module Area (m)
- 4.37451570 Isc (Short Circuit Current)
- 42.9261527 Voc (Open Circuit Volts)
- 3.96080925 Imp (Max Power Point Current)
- 33.6802686 Vmp (Max Power Point Volts)
- 0.00040064 uIsc A/K (Temp. Coefficient of Current)
- 0.1523657 uVoc V/K (Temp. Coefficient of Voltage)
- 1.02572676 Diode Idealty Factor
- 72 Number of Cells in Series per Module
- 1 Number of Parallel Cell Strings per Module

The "Array I-V Curve at 25C ambient, 1000 W/m2" graph shows the relationship between current (Amps) and power (Watts) versus voltage (Volts). The x-axis represents Voltage (0V to 50V), the left y-axis represents Current (0.0 to 4.5 A), and the right y-axis represents Power (0 to 100 W). The blue curve represents the current (Isc), the green curve represents the power (Pmp), and the bottom axis represents voltage (Voc).

At the bottom of the interface, there is a "Done." button and a "Run Simulation" button. The status bar at the bottom indicates "2002 SouthWall.pvs" and "0.000% 0.000".

Scope

- Test Specimens
 - Monocrystalline Custom-Fabricated BIPV Module
 - Silicon Film Custom-Fabricated BIPV Module
 - Triple-Junction Amorphous Module

- Laboratories
 - Sandia National Laboratories (SNL)
 - National Institute of Standards and Technology (NIST)

- Measured Parameters
 - Temperature Coefficients – α_{ISC} , α_{IMP} , β_{VOC} , β_{VMP}
 - Response to Variations in Incident Angle and Absolute Air Mass
 - Performance at Standard Reporting Conditions
 - 25 °C Cell Temperature
 - 1.5 Absolute Air Mass
 - 0° Angle of Incidence
 - 1000 W/m² Irradiation Level

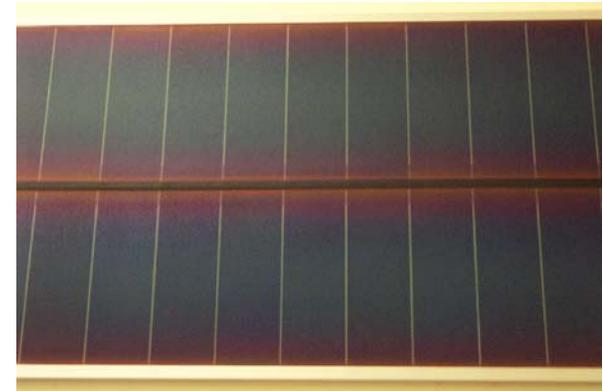
Photovoltaic Modules



Monocrystalline



Silicon Film



Triple-Junction Amorphous

Module Specifications			
Cell Technology	Monocrystalline	Silicon Film	Triple-Junction Amorphous
Module Dimensions (m x m)	1.38 x 1.18	1.38 x 1.18	1.37 x 1.48
Front Cover	6 mm glass	6 mm glass	Tefzel
Ethylene Vinyl Acetate Encapsulant (EVA)	X	X	X
Backsheet/Color	Tedlar/Charcoal	Tedlar/Charcoal	Stainless Steel
Cell dimensions (mm x mm)	125 x 125	150 x 150	119 x 340
Number of Cells (in series)	72	56	44
Cell Area (m ²)	1.020	1.341	1.780
Aperture Area (m ²)	1.682	1.682	2.108
Coverage Area (m ²)	1.160	1.371	1.815

Test Facilities



Sandia National Laboratories

- Fixed
- Multiple Tracking Modes
- IV Curve Traces-Programmable Power Supplies
- Radiation Measurements
 - Total Eppley PSP and Silicon Reference Cell
 - Beam – Eppley Pyreheliometer
 - Spectral – LiCor 1800 (300 nm – 1100 nm)
 - Silicon Primary Reference Cell
- Temperature Measurements
 - Calibrated Type-T Thermocouples

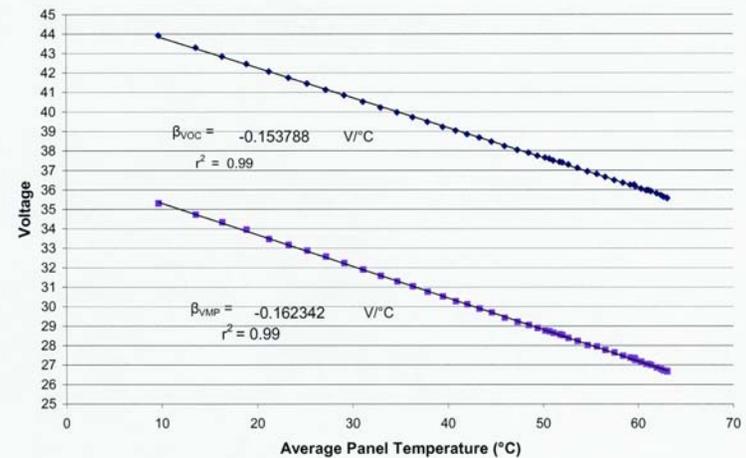
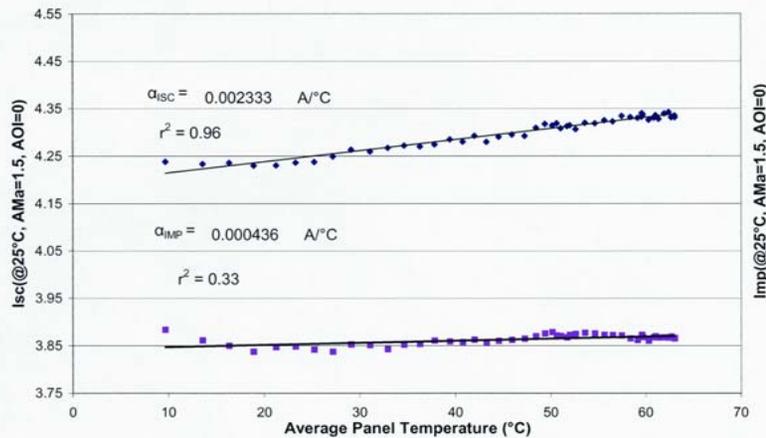
National Institute of Standards and Technology

- Mobile
- Multiple Tracking Modes
- IV Curve Traces – Raydec IV Curve Tracer Unit
- Radiation Measurements
 - Total – Eppley PSP
 - Beam-Eppley Pyreheliometer
 - Spectral – LiCor 1800 (300nm-1100nm)
- Temperature Measurements
 - Calibrated Type-T Thermocouples
 - Electronic Ice Point Reference



Temperature Coefficients

- Quantify Influence of Temperature on Module Performance
 - Short Circuit and Maximum Power Currents
 - Open Circuit and Maximum Power Voltages
- Test Procedure
 - Clear Sky Conditions, Wind Speed <2 m/s
 - Shield PV Module Until Module Temperature Approaches Ambient
 - Remove Radiation Shield
 - Collect Current, Voltage, and Temperature Data During Module Heating



Incident Angle Function

- Quantifies Relationship Between Short Circuit Current (I_{sc}) and Incident Angle
- Applicable Only to Beam Irradiance
- Test Procedure
 - Clear Sky conditions, Wind Speed < 2m/s
 - Measure I_{sc} at Various Incident Angles
 - Measure Beam Irradiance Using Separate Tracker

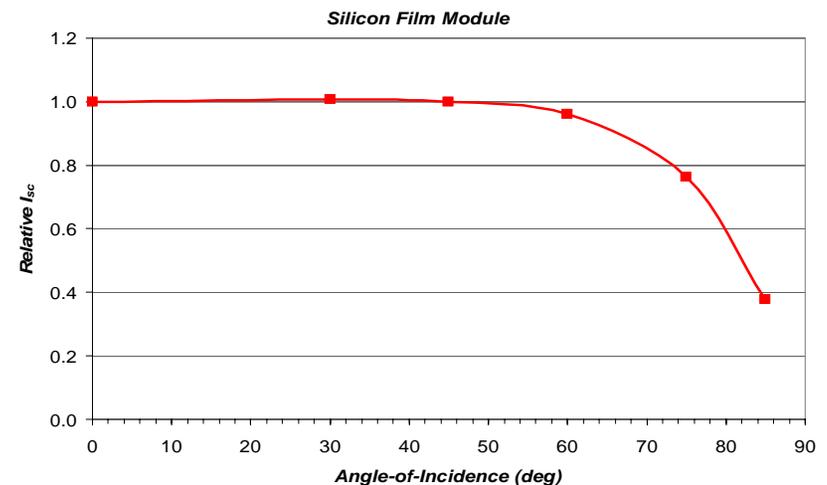
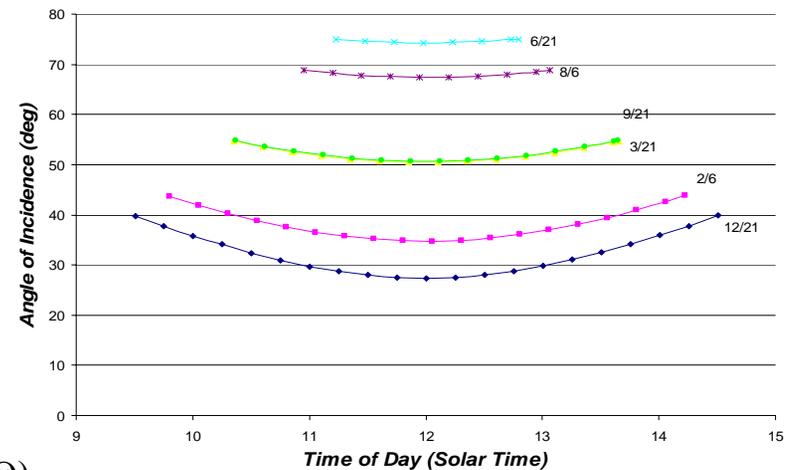
Data Analysis

- Determine Diffuse Radiation -> $E_{diff} E_{tpoa} - E_{dni} \cos(\Theta)$
- Correct Measured I_{sc} values to 25 °C
- Complete Relative short Circuit Current

$$f_2(AOI) = \frac{\frac{E_o}{I_{sco}} I_{sc}(AMa = 1.5, T = 25^\circ C) - E_{diff}}{E_{dni} \cos(AOI)}$$

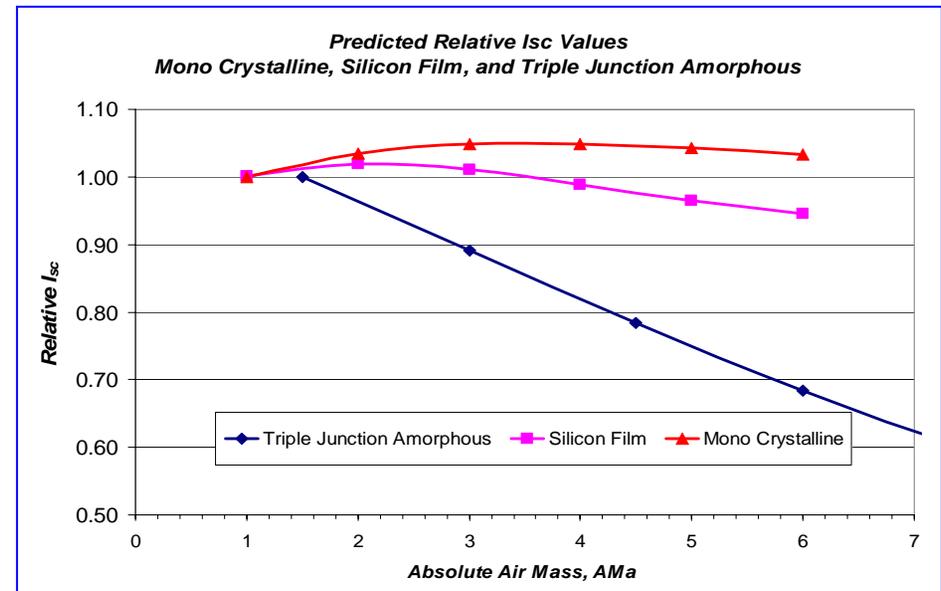
where

- E_{tpoa} = Total irradiance on module, W/m^2
- E_o = reference irradiance, $1000 W/m^2$
- I_{sc} = corrected short circuit current, A
- E_{diff} = diffuse irradiance on panels, W/m^2
- I_{sco} = current at reference conditions, A
- E_{dni} = direct normal irradiance, W/m^2
- AOI = angle of incidence, θ



Air Mass Function

- Quantifies Relationship Between Short Circuit Current (I_{sc}) and Air Mass
- $AM = \left[\cos(Z_s) + 0.5057 \cdot (96.08 - Z_s)^{-1.634} \right]^{-1}$
- Attempts to Capture Influence of Time-of-Day Solar Spectral Variation
- Test Procedure
 - Clear Sky Conditions, Wind Speed < 2m/s
 - Measure Short circuit Current, I_{sc} , Track Sun Throughout Day (AOI = 0°) Throughout Day
- Data Analysis
 - Correct I_{sc} Values to 25 °C and 1000 W/m²
- Compute Relative $I_{sc} = I_{sc}(AMa = 1.5)$ to 25 C and 1000 W/m²

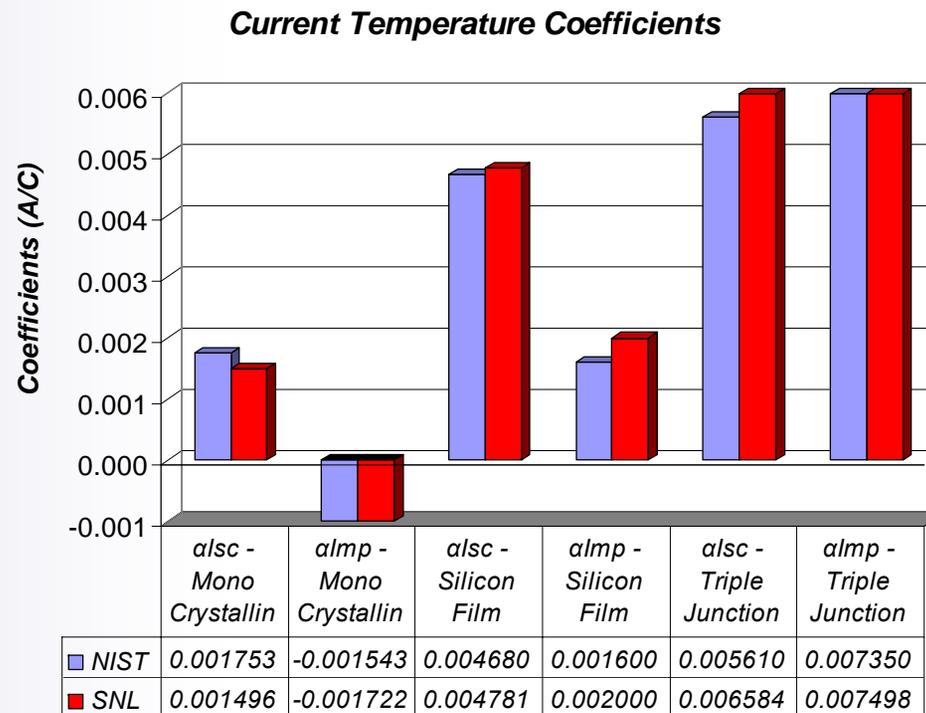


Air Mass Functions for Modules

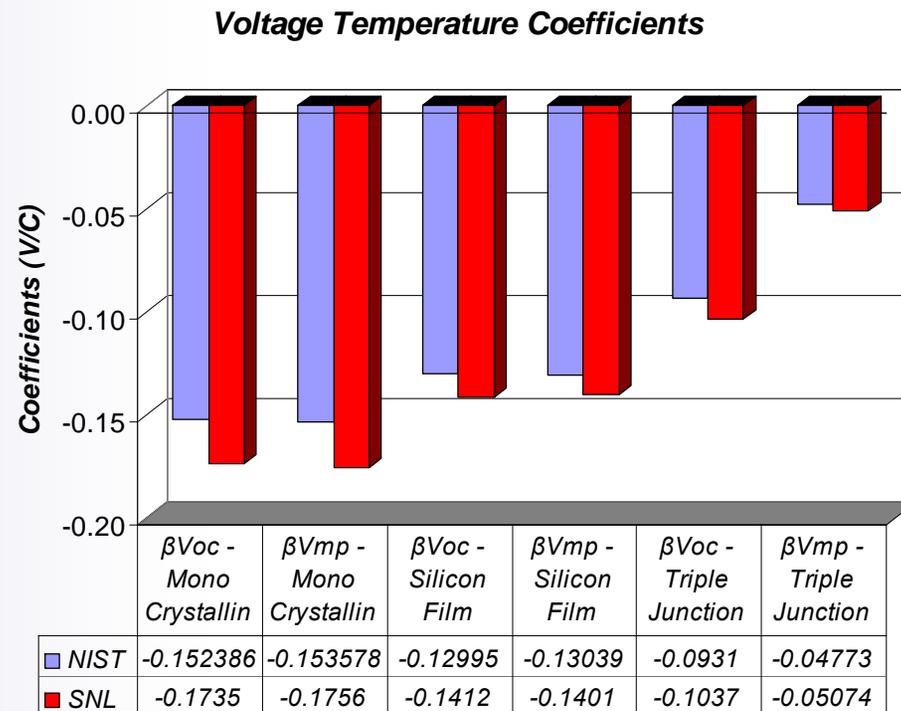
Performance at Standard Reporting Conditions

- PV Module Performance at Standard Reporting Conditions
 - Cell Temperature 25 °C
 - Solar Irradiance 1000 W/m²
 - Absolute Air Mass 1.5
- Permits Comparison of Results for a Given Module
- Permits PV Module Comparisons
- Procedure
 - Correct Measurements to 25 °C
 - Correct Measurements to 1000 W/m²
 - Correct Measurements to Absolute Air Mass of 1.5

Comparison of NIST and SNL Measured Current Temperature Coefficients

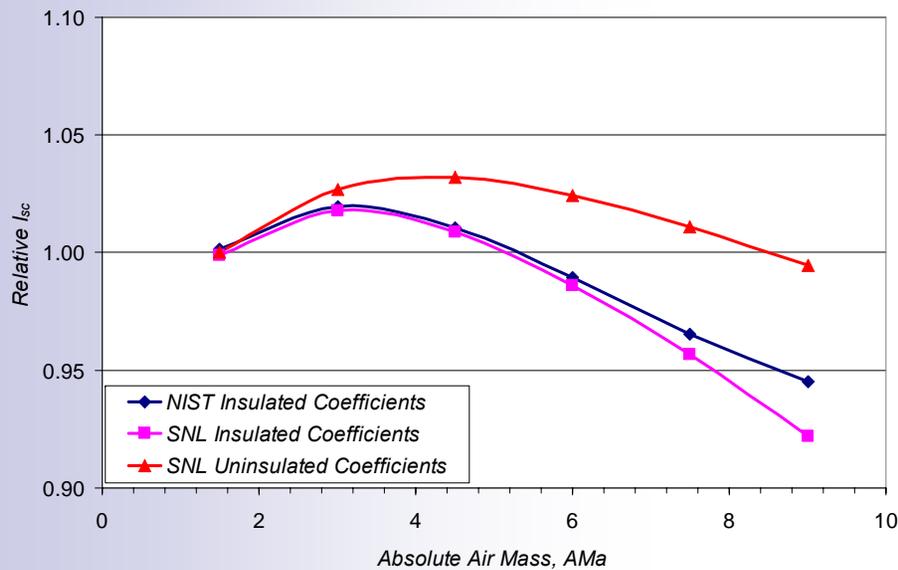


Comparison of NIST and SNL Measured Voltage Temperature Coefficients

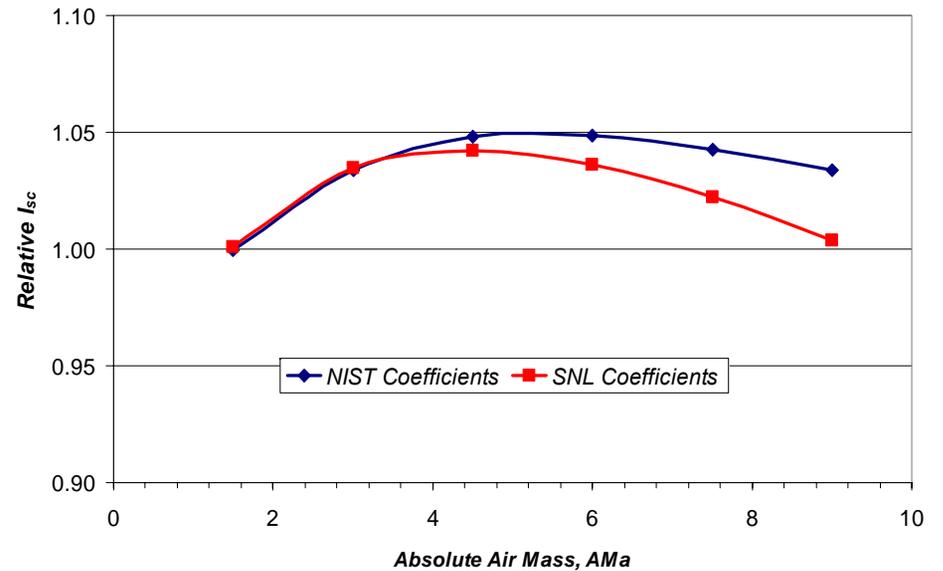


Air Mass Function Comparison

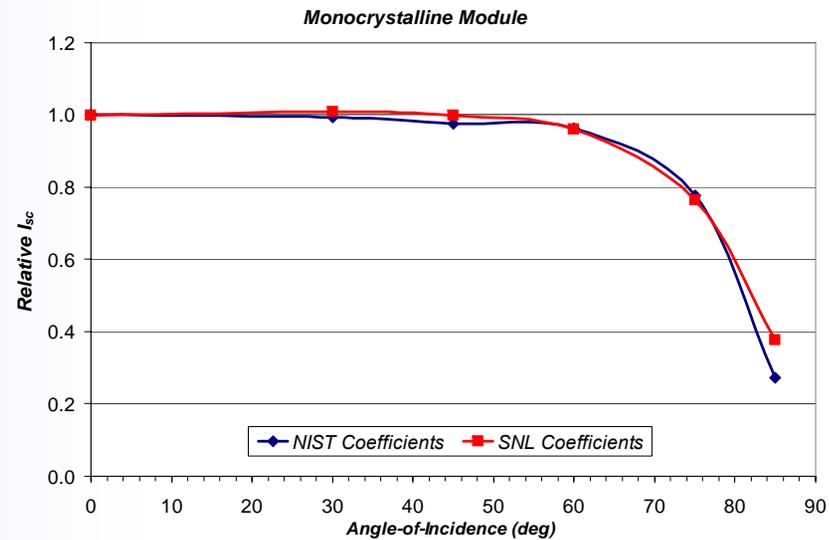
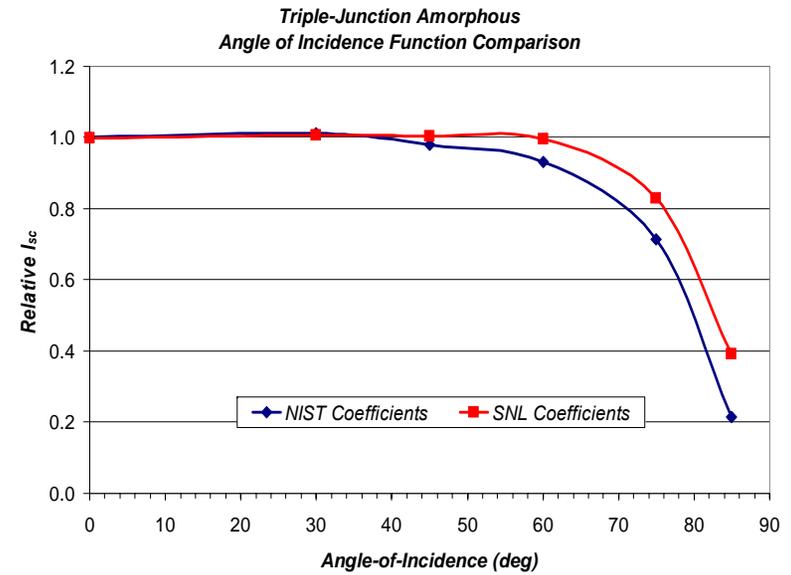
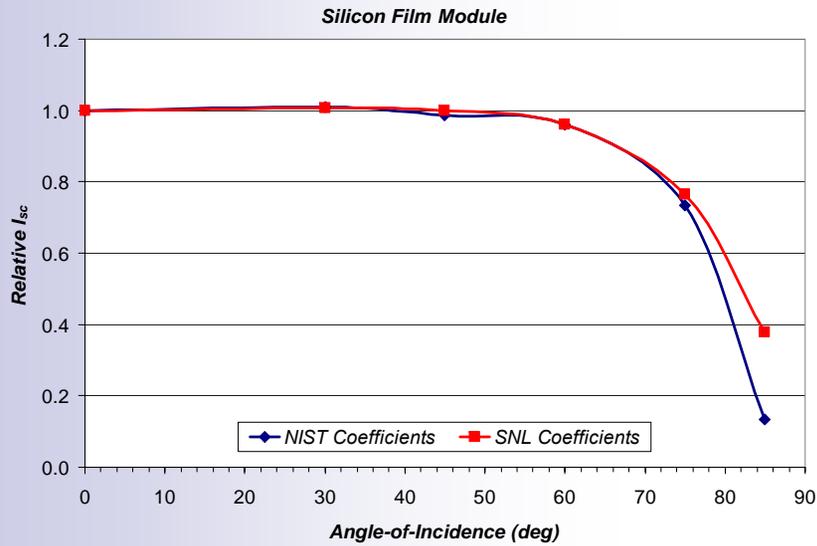
Silicon Film Module



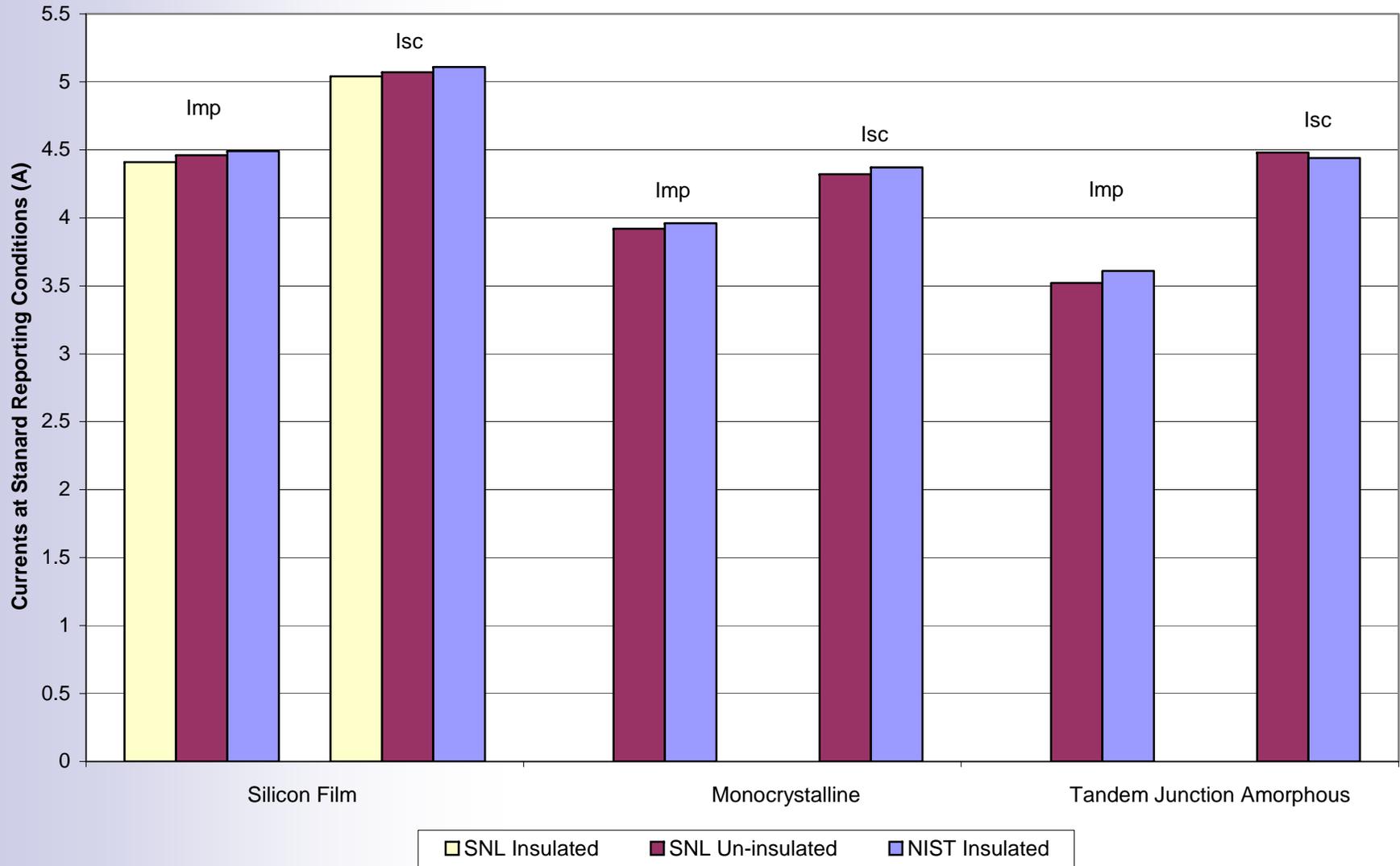
NIST and SNL Predicted Relative I_{sc} Values
Mono Crystalline Module



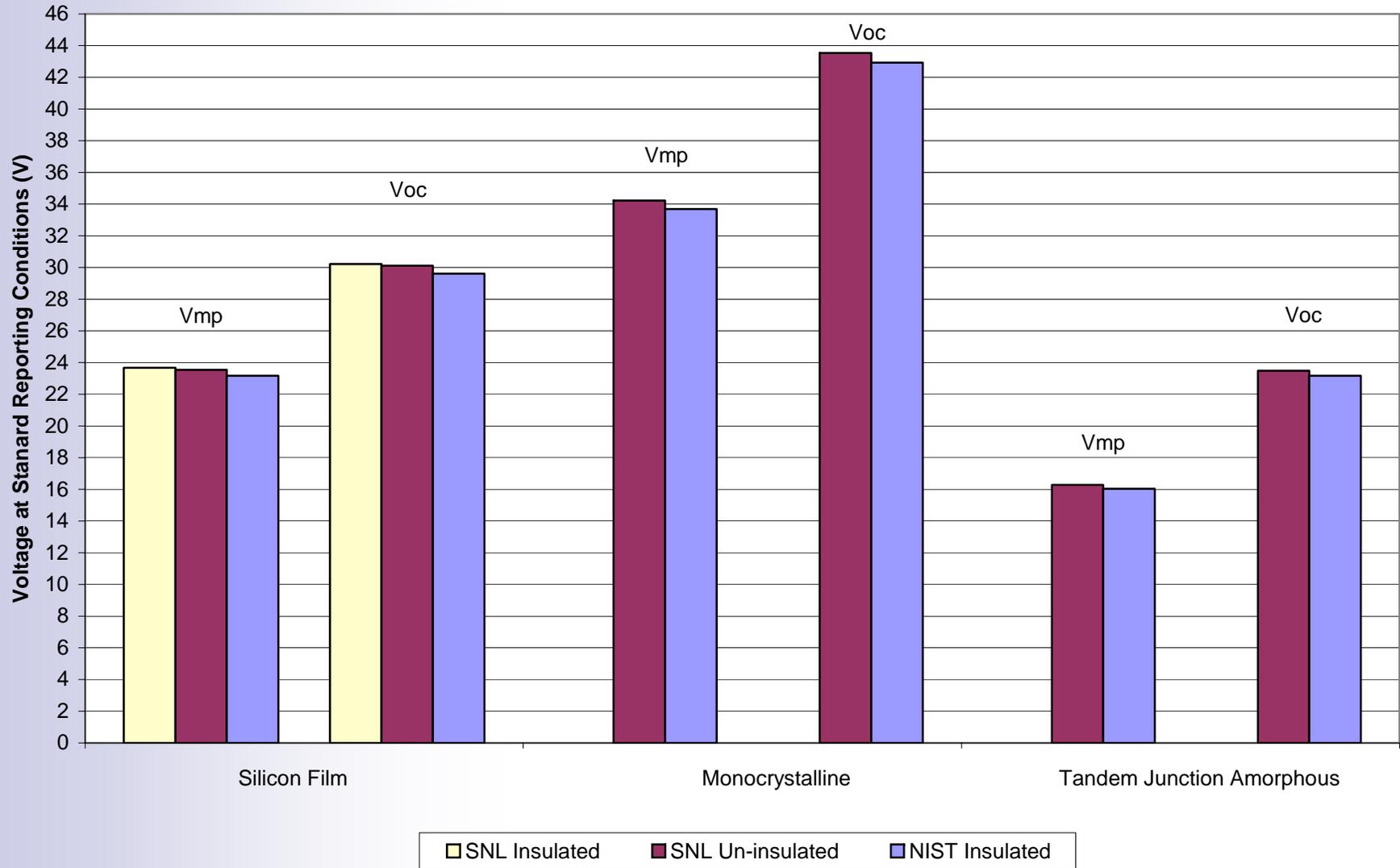
Incident Angle Response Comparison



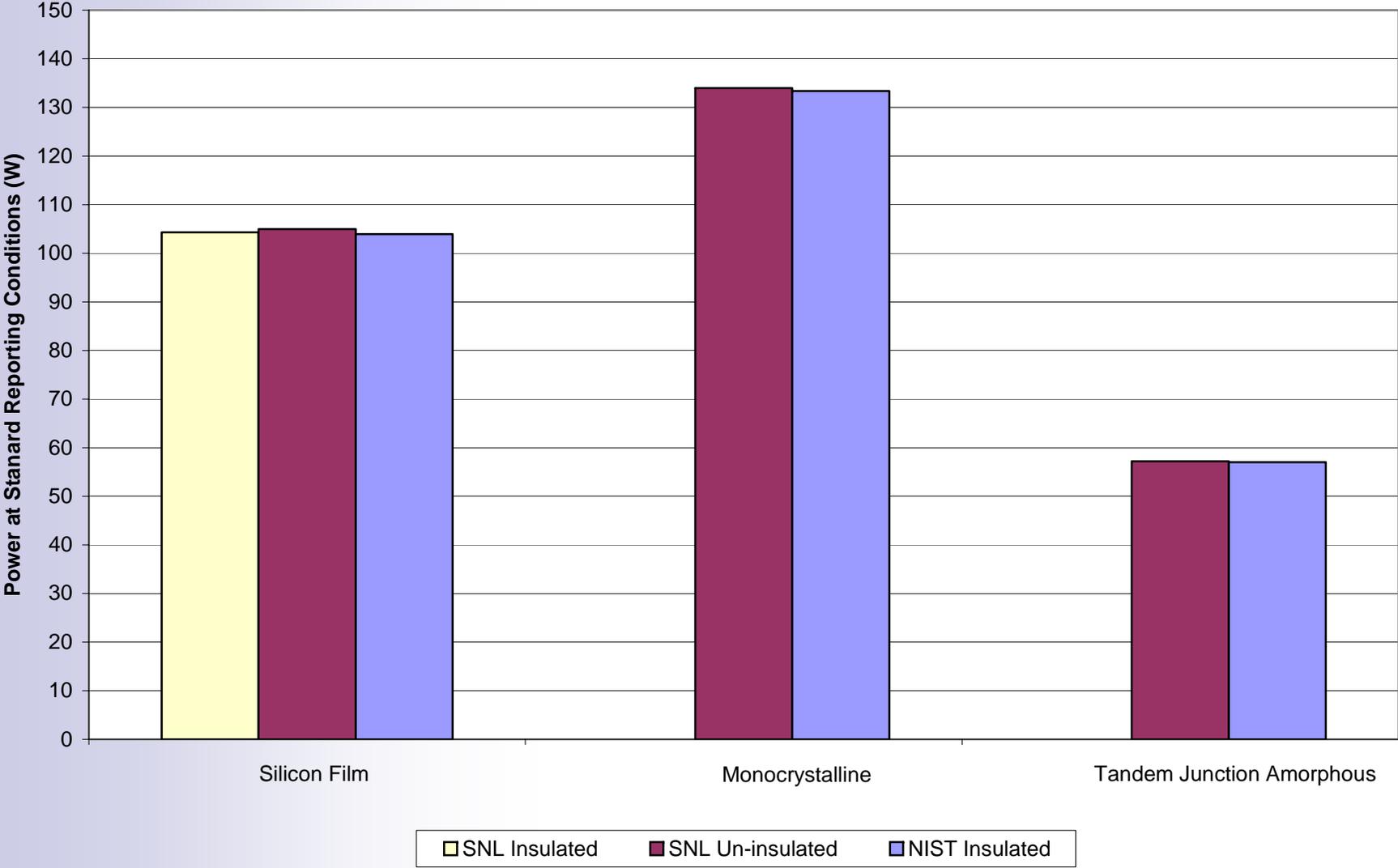
NIST - SNL Measurement Comparisons



NIST - SNL Measurement Comparisons



NIST - SNL Measurement Comparisons



BIPV Comparisons at Standard Reporting Conditions

Summary Of Measured Photovoltaic Module Parameters								
Standard Reference Condition		Silicon Film			Monocrystalline		Triple Junction Amorphous	
		NIST Insulated	SNL Un-insulated	SNL Insulated	NIST Insulated	SNL Un-insulated	NIST Insulated	SNL Un-insulated
P_{mpo}	(W)	103.96	104.95	104.32	133.40	133.99	57.04	57.20
I_{sco}	(A)	5.11	5.07	5.04	4.37	4.32	4.44	4.48
V_{oco}	(V)	29.61	30.12	30.23	42.93	43.53	23.16	23.49
I_{mpo}	(A)	4.49	4.46	4.41	3.96	3.92	3.61	3.52
V_{mpo}	(V)	23.17	23.53	23.66	33.68	34.23	16.04	16.27
NIST Measurement Uncertainties					SNL Measurement Uncertainties			
$P_{mpo} - \pm 2.2 \%$	$I_{sco} - \pm 1.7 \%$	$P_{mpo} - \pm 2.2 \%$			$P_{mpo} - \pm 2.3 \%$	$I_{sco} - \pm 1.9 \%$		
$V_{oco} - \pm 1.1 \%$	$I_{mpo} - \pm 1.6 \%$	$V_{oco} - \pm 1.1 \%$			$V_{oco} - \pm 1.0 \%$	$I_{mpo} - \pm 2.0 \%$		
$V_{mpo} - \pm 1.4 \%$		$V_{mpo} - \pm 1.4 \%$			$V_{mpo} - \pm 1.1 \%$			
Values of uncertainty represent the expanded uncertainty using a coverage factor of 2.								

Summary

- Performance of Three PV modules Measured Under Outdoor Conditions
 - Monocrystalline Custom Fabricated BIPV Module
 - Silicon Film Custom Fabricated BIPV Module
 - Triple-Junction Amorphous Module
- Two Different Laboratories
 - Sandia National Laboratories
 - National Institute of Standards and Technology
- Temperature Coefficients
 - Varied From 2% to 17%
 - Impact on Panel Performance Small < 2%
- Air Mass Functions
 - Agreement Within 4%
- Incident Angle Functions
 - Reasonable Agreement at AOI < 70°
 - Significant Difference at > 70°
- Performance at Standard Reporting Conditions
 - Short Circuit Current < 2%
 - Maximum Power Current < 2%
 - Open Circuit Voltage < 2%
 - Max Power Voltage < 2%